REMARKS

Claims 1-26 are all the claims currently pending in the present application. By this Amendment, claims 1, 5, 7-11, and 16-17 are amended, and new claims 18-26 are added. An excess claims fee letter and fee are attached. The amendments introduce no new matter.

It is noted that the claim amendments, if any, are made only to assure grammatical and idiomatic English and improved form under United States practice, and are not made to distinguish the invention over the prior art or narrow the claims or for any statutory requirements of patentability. Further, Applicant specifically states that no amendment to any claim herein should be construed as a disclaimer of any interest in or right to an equivalent of any element or feature of the amended claim.

Claims 1-9 and 13-17 stand rejected under 35 U.S.C. §103(a) over Jones (US 6,959,028) in view of Po (US 4,852,117). Claims 10-12 stand rejected under 35 U.S.C. §103(a) over Jones in view of Po, and further in view of Margalit, et al. (US 6,668,006). These rejections are respectfully traversed in the following discussion.

THE CLAIMED INVENTION

The claimed invention, as exemplarily defined by independent claim 1, is directed to a tunable laser. The tunable laser includes a multiple ring resonator, an LD-side waveguide, a reflection-side waveguide, a single board, a reflection film, a laser diode chip, and a tuning device.

The multiple ring resonator includes a plurality of ring resonators. The ring resonators are constituted with ring-type waveguides. The ring-type waveguides have optical path lengths different from each other. The ring-type waveguides are coupled through an

optical-coupling device.

The LD-side waveguide has one end connected to one of the plurality of ring resonators through an optical-coupling device.

The reflection-side waveguide has one end connected to a different one of the plurality of ring resonators through an optical-coupling device.

The ring resonator, the LD-side waveguide and the reflection-side waveguide are formed on the single board.

The reflection film is provided to the other end of the reflection-side waveguide.

The laser diode chip has a low reflection film formed on one of two opposing emission end faces, which is optically coupled to the LD-side waveguide through the low reflection film.

The tuning device changes a resonance wavelength of the multiple ring resonator.

In a conventional communication system, DFB-LD (Distributed feedback laser diode) performing uniaxial-mode oscillation has been used widely because it is easy to handle and highly reliable. In the DFB-LD, a diffraction grating with a depth of about 30 nm is formed over the entire region of a resonator, and a stable uniaxial mode oscillation can be obtained with a wavelength that corresponds to a product of the diffraction grating period and twice the equivalent refractive index. However, the DFB-LD is not capable of performing tuning over a wide range of the oscillation wavelengths, so that the WDM system is constituted by using articles that are different only in terms of the wavelength for each ITU grid. Thus, it is necessary to use different articles for each wavelength, which causes an increase in the cost for managing the articles for each wavelength, and requires a surplus stock for dealing with breakdown, etc. Furthermore, if a regular DFB-LD is used in the ROADM that switches the

optical paths by the wavelengths, the tunable width of the range of the wavelengths that can be changed with a temperature change is limited to about 3 nm. Thus, it becomes difficult to constitute the optical network that utilizes the characteristic of the ROADM, which is to use the wavelength resource actively.

For overcoming such shortcomings of the current DFB-LD and achieving uniaxial-mode oscillation with a wide range of wavelengths, conventional tunable lasers have been used. Tunable lasers can be classified roughly into two types; one is a type where a tuning mechanism is provided within a laser element, and the other is a type where a tuning mechanism is provided outside the laser element.

For the former case, there has been proposed a DBR-LD (Distributed Bragg reflector laser diode) in which an active region for generating the gain and a DBR region for generating reflection by the diffraction grating are formed within the same laser element. The tunable range of the DBR-LD is about 10 nm at the most. Further, there has also been proposed a DBR-LD using non-uniform diffraction grating, in which the active region for generating the gain and the DBR regions sandwiching the active regions from the front and rear are formed within the same laser element. The DBR regions in the front and rear generate a great number of reflection peaks by the non-uniform diffraction grating, and the intervals of the reflection peaks are slightly shifted in the front and the rear. So-called "Vernier effect" can be achieved through this structure, so that it becomes possible to perform tuning over an extremely wide range of wavelengths. The DBR-LD using the non-uniform diffraction grating has achieved tuning action of more than 100 nm and quasi-continuous tuning action of 40 nm.

For the latter case, there has been proposed a tunable laser that returns the light of a

certain wavelength by rotating the diffraction grating provided outside the laser element.

However, in conventional tunable lasers, there are shortcomings such as generation of mode hopping, complicated method of wavelength control, low oscillation resistibility, high price due to an increase in the number of elements, etc. Therefore, it has been difficult to put them into a practical use.

In the DBR-LD, carrier injection is performed to the DBR region for changing the refractive index in the DBR region for achieving the tuning action. Thus, if crystal defects increase due to the injection of the electric current, the proportion of changes in the refractive index with respect to the current injection fluctuates strikingly. Therefore, it is difficult to maintain the laser oscillation with a constant wavelength over a long time. Furthermore, with the current process technique of a compound semiconductor, inch-up of two inches or more is impossible. Thus, it is difficult to cut the cost from that of the current state with the laser element that has become complicated and large-scaled.

In the laser element where the tuning mechanism is provided outside the laser element, mode jump is easily generated by the oscillation. Thus, it requires a large-scaled oscillation-resistant mechanism for avoiding the mode jump, which results in large-scaled module and increased price.

The present invention, on the other hand, overcomes obstacles for practical use, and provides a highly reliable, high-performance, and low-price tunable laser.

The light emitted from the LD chip returns through the route of the low reflection film → the LD-side waveguide → the multiple ring resonator → the reflection-side waveguide → the reflection film → the reflection-side waveguide → the multiple ring resonator → the LD-side waveguide → the low reflection film. The wavelength of this return light is the

resonance wavelength of the multiple ring resonator. The reason is that the FSRs (Free Spectral Range) of each ring resonator constituting the multiple ring resonator are slightly different from each other, so that there generates still larger reflection at the wavelength (resonance wavelength) where the periodic changes of the reflections (transmissions) generated in each of the ring resonators meet with each other. The wavelength where the periods become consistent changes according to the circumferential lengths of each ring resonator and the changes in the waveguide refractive indexes, so that efficient tuning action can be obtained. The waveguide refractive index can be changed by the thermooptic effect. The thermooptic effect is a phenomenon in which the refractive index of a material is increased by heat, which can normally be observed in any kinds of materials. In other words, it is possible to change the resonance wavelength of the multiple ring resonator by utilizing the temperature properties of a plurality of ring resonators. The tuning device may be either type that heats or cools the ring resonator. As described above, the present invention constitutes the multiple ring resonator through connecting a plurality of ring resonators with slightly different circumferences in series, and utilizes the Vernier effect generated thereby.

With the tunable laser according to the present invention, the laser light of an extremely wide range of wavelengths can be obtained by mounting the LD chip on the board where the multiple ring resonator is formed and by changing the resonance wavelength through control of the temperature of the multiple ring resonator. Furthermore, it is highly reliable since there is no injection of electric current to the semiconductor laser and no mechanical movable member used therein. Moreover, it can be formed by simply mounting the LD chip on the board, so that it can be manufactured easily at low cost.

The use of the laser structure according to the present invention achieves the tuning

action over a wide range of wavelengths that cannot be achieved with a regular DFB-LD, through a simple structure using no external mirror that has been used conventionally. Furthermore, there is no movable part provided therein, unlike the regular tunable laser of the external mirror type. Thus, high oscillation impact characteristic can be achieved in addition to achieving high reliability. Moreover, the change in the property over time is extremely smaller compared to the system that injects electric current to the semiconductor waveguide, because the refractive indexes of the ring-type waveguides of the ring resonator are changed for tuning the wavelengths. A tunable laser according to the present invention is thus superior to the conventional tunable laser in many respects, and it can be manufactured at a low cost.

THE PRIOR ART REJECTIONS

The Jones Reference

The Examiner alleges that certain features of the claims are disclosed by Jones. Applicant submits that there are features of the claims as recited which are neither taught nor suggested by Jones.

Claims 1-9 and 13-17 stand rejected under 35 U.S.C. §103(a) over Jones in view of Po. Claims 10-12 stand rejected under 35 U.S.C. §103(a) over Jones in view of Po, and further in view of Margalit. Applicant respectfully traverses these rejections.

Applicant submits that Jones, both alone and in combination with Po, fails to disclose or suggest at least "A tunable laser, comprising: a multiple ring resonator in which a plurality of ring resonators, which are constituted with ring-type waveguides having optical path lengths different from each other, are coupled through an optical-coupling device; an LD-side

waveguide whose one end is connected to one of the plurality of ring resonators through an optical-coupling device; a reflection-side waveguide whose one end is connected to other one of the plurality of ring resonators through an optical-coupling device; a single board on which the ring resonator, the LD-side waveguide and the reflection-side waveguide are formed; a reflection film provided to other end of the reflection-side waveguide; a laser diode chip having a low reflection film formed on one of two opposing emission end faces, which is optically coupled to the LD-side waveguide through the low reflection film; and a tuning device for changing resonance wavelength of the multiple ring resonator," as recited in independent claim 1.

The Examiner alleges only that Jones discloses, "*a LD-side waveguide (44) whose one end is connected to one end of the ring resonator through evanescent coupling (col. 3 lines 56-63.*" Office Action, p. 2.

Applicant submits that Jones fails to disclose or suggest an LD-side waveguide whose one end is connected to one of the plurality of ring resonators through an optical-coupling device , as recited in the claim.

Evanescent coupling, as disclosed by Jones, is a process by which electromagnetic waves are transmitted from one medium to another by means of the evanescent, exponentially decaying electromagnetic field. Evanescent coupling is usually accomplished by placing two or more electromagnetic elements such as optical waveguides close together so that the evanescent field generated by one element does not decay much before it reaches the other element. With waveguides, if the receiving waveguide can support modes of the appropriate frequency, the evanescent field gives rise to propagating wave modes, thereby connecting (or coupling) the wave from one waveguide to the next.

Evanescent wave coupling is fundamentally identical to near field interaction in electromagnetic field theory. Depending on the impedance of the radiating source element, the evanescent wave is either predominantly electric (capacitive) or magnetic (inductive), unlike in the far field where these components of the wave eventually reach the ratio of the impedance of free space and the wave propagates radiatively. The evanescent wave coupling takes place in the non-radiative field near each medium and as such is always associated with matter, i.e. with the induced currents and charges within a partially reflecting surface. This coupling is directly analogous to the coupling between the primary and secondary coils of a transformer, or between the two plates of a capacitor. Mathematically, the process is the same as that of quantum tunneling, except with electromagnetic waves instead of quantum-mechanical wavefunctions.

In contrast, the present invention utilizes an optical coupling device such as a directional coupler. See: Fig. 1, references 121, 122, 123. Directional couplers couple part of the transmission power in a transmission line by a known amount out through another port, often by using two transmission lines set close enough together such that energy passing through one is coupled to the other.

Jones fails to disclose or suggest any optical coupling device analogous to 121, 122, 123. Instead, Jones discloses only that waveguides 44 and 46 are in proximity to micro-ring resonator 40 so as to use evanescent coupling, as cited by the Examiner. Jones, Fig. 5; col. 3, lines 33-37, 55-62.

The Examiner alleges that Jones discloses, "*a reflection film (an end of Bragg grating 42 having high reflectivity is equivalent to a reflection film as indicated in figure 4 as a*

reflective filter) provided to the other end of the reflection-side waveguide." Office Action, p. 2.

However, Jones discloses only a Bragg grating. A Bragg grating is a type of distributed Bragg reflector constructed in a short segment of optical fiber that reflects particular wavelengths of light and transmits all others. This is achieved by adding a periodic variation to the refractive index of the fiber core, which generates a wavelength specific dielectric mirror. A fiber Bragg grating can therefore be used as an inline optical filter to block certain wavelengths, or as a wavelength-specific reflector.

Jones discloses, "*The reflection spectrum of the Bragg grating 24 has a free spectral range that is different from the free spectral range of the ring resonator 40. For instance in the above example the free spectral range of the ring 40 was 13 nm. In such an example, the free spectral range of the Bragg grating 42 may be, for example, 11 nm*." Jones, col. 3, line 64 – col. 4, line 2. Further, "*As shown in FIG. 7, the transmission spectrum of the ring resonator 40 and the reflective spectrum of the Bragg grating 42 act as a kind of vernier. The Bragg grating 42 only reflects light having a wavelength corresponding to one of the transmission peaks received from the ring resonator 42. This reflected light is fed back into the gain chip 22, is the only wavelength of light that experiences stimulated emission, and, thus, is the wavelength that lases*." Jones, col. 4, lines 22-29.

Jones specifies that either the Bragg grating must be tuned with the ring resonator to specific wavelengths, or else carrier injection must be utilized: "*In the example of FIG. 5, the Bragg grating 42, the ring resonator 40 and the waveguides 44, 46 are formed in a single substrate 50. The substrate 50 may be constructed of any suitable material such as, for example, silicon. If silicon is used as the substrate 50 for the resonator 40 and the grating*

42, tuning of the refractive index can be achieved by heating the substrate (i.e., utilizing the thermo-optic effect), and/or by modulating the number of free carriers (i.e., carrier injection). In the former case, either the entire substrate 50 may be heated to effect the indices of refraction of both the ring resonator 40 and the Bragg grating 42, or localized heating may be employed to adjust the index of refraction of one of the resonator 40 and the grating 42 more heavily than the index of refraction of the other of the resonator 40 and the grating 42. In the latter case (i.e., carrier injection), a conventional control circuit (not shown) such as a programmable processor driving a conventional current source may be coupled to the ring resonator 40 and/or the Bragg grating 42 to apply a controlled current to the device(s) to thereby change the effective optical path length through the affected filter 26, 28." Jones, col. 4, lines 34-54.

In contrast, the present invention uses a high-reflection film which requires no tuning. "The high reflection film 16 is made of a dielectric multilayer film or a metal film of gold or the like, which is formed on the side face of the PLC board 15. The high reflection film 16 may be any reflection film as long as it has a characteristic capable of reflecting the laser light sufficiently." Specification, p. 14, lines 1-6. Further, the present invention avoids carrier injection.

Such features enable the present invention to achieve the desired effects with reduced complexity, increased efficiency and at reduced cost.

Thus, Jones fails to disclose or suggest at least these features of the claims.

The Po Reference

The Examiner alleges that certain features of the claims are disclosed by Po.

Applicant submits that there are features of the claims as recited which are neither taught nor suggested by Po.

Claims 1-9 and 13-17 stand rejected under 35 U.S.C. §103(a) over Jones in view of Po. Claims 10-12 stand rejected under 35 U.S.C. §103(a) over Jones in view of Po, and further in view of Margalit. Applicant respectfully traverses these rejections.

The Examiner admits that Jones fails to disclose or suggest a plurality of ring resonators, which are constituted with ring-type waveguides having optical path lengths different from each other, as recited in the claims. The Examiner relies on Po to overcome the deficiencies of Jones.

The Examiner alleges that Po discloses, "*a multiple ring resonator in which a plurality of ring resonators (pump loop 18" and additional loop 136), which are constituted with ring-type waveguides having optical path lengths different from each other ("the additional cavity is of slightly different length"), are coupled through an optical-coupling device (lateral coupling 1414 & 142) (col.. 13 lines 50-64).*" Office Action, p. 3.

Po discloses, "*As in the multiple filter arrangements, the additional cavity is of slightly different length to select one line of the emissive region of the first loop by means of coresonance.*" Po, col. 13, lines 58-61.

The Examiner alleges that Po discloses, "*wherein, in the plurality of ring resonators, diameters of the ring waveguides are set so that intervals of reflection peaks appearing periodically become different, and there generates resonance at a meeting point of the reflection peaks (inherent property of two ring resonators with different diameters coupled together).*" Office Action, p. 4.

As recited in claims 20 and 26, <u>the resonant frequency is adjusted only by changing</u>

the refractive properties of the ring-type waveguides. No carrier injection is used. This reduces complexity and cost while increasing stability and reliability.

As recited in claim 21, the refractive properties of each of the ring-type waveguides are adjusted by temperature.

As recited in claims 23 and 24, the temperature is adjusted by a simple means such as film-like heaters, which can be formed directly on the board, thus further reducing complexity and cost.

In contrast, Po discloses, "*For tuning and gross stabilization, the temperature of the chamber 172 is varied. For fine tuning, the piezo-electyric members 174 and 176 are employed to change the path length of the cavities. The fine tuning operation is effected by dithering the piezo member 174 from an A.C. signal generator 180 to slightly and rapidly vary the optical path length of the short cavity 170 such that the resonant lines of the short cavity 170 are correspondingly dithered.*" Po, col. 14, lines 53-61.

Thus, Po fails to disclose or suggest at least these features of the present invention, both alone and in combination with Jones.

Therefore, Applicant respectfully requests the Examiner reconsider and withdraw the rejection of claims 1-9 and 13-17 over Jones in view of Po, and of claims 10-12 over Jones in view of Po and further in view of Margalit.

CONCLUSION

In view of the foregoing, Applicant submits that claims 1-26, all the claims pending in the application, are patentably distinct over the prior art of record and are allowable, and that the application is in condition for allowance. Such action would be appreciated.

Should the Examiner find the application to be other than in condition for allowance, the Examiner is requested to contact the undersigned attorney at the local telephone number listed below to discuss any other changes deemed necessary for allowance in a telephonic or personal interview.

To the extent necessary, Applicant petitions for an extension of time under 37 CFR §1.136. The Commissioner is authorized to charge any deficiency in fees, including extension of time fees, or to credit any overpayment in fees to Attorney's Deposit Account No. 50-0481.

Respectfully Submitted,

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